

Mars Small Spacecraft Studies

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Scientifically Compelling

Mars small spacecraft can accomplish decadal class science while being complementary to Flagship missions in type of science investigation.

Low Cost

Mars small spacecraft can get to Mars for costs of ~\$100-300M, including phases A-D and all launch costs.

Technically Feasible

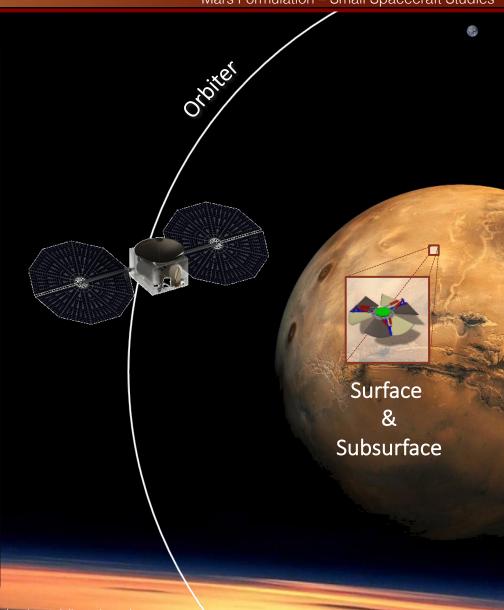
Mars small spacecraft can meet mass/volume constraints that allow reaching Mars via "rideshare" launches to GTO and/or new classes of small commercial launch vehicles

Small affordable spacecraft missions with new launch modes are possible and can deliver Decadal-class science complementary to Flagship missions.

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Motivation and Objectives

- Desire for continued science investigations during MSR with smaller, affordable missions
- Small spacecraft can augment MSR by providing frequent, low cost access to compelling science investigations at Mars
- Identify science mission concepts suitable for small spacecraft implementation
- Include concepts to target Mars orbit as well as the Martian surface/subsurface



Compelling Science from Small Spacecraft



Mars Formulation – Small Spacecraft Studies

Fundamental & New Single Measurements

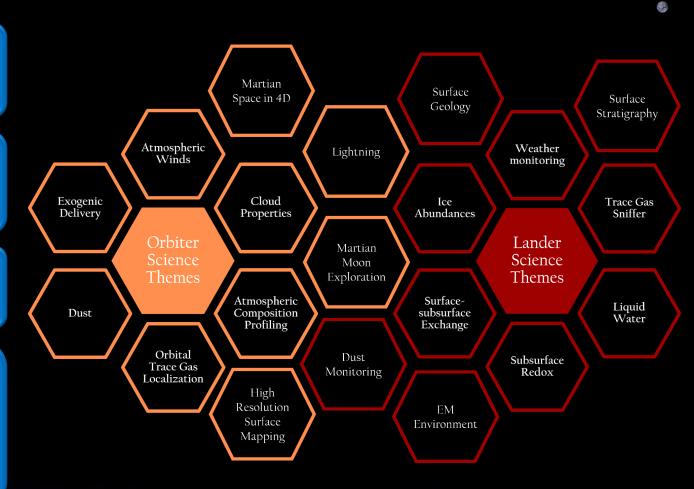
Targeted Science

One instrument drives all.

Special Landing
Zones are Enabled

3D/4D is the Science

- Global Coverage
- Networks
- Causality
- Processes
- Scouts



High value science at low cost, complementary to MSR.

Compelling Science from Small Spacecraft: Key Findings



Mars Formulation – Small Spacecraft Studies

Fundamental & New Single Measurements

Groundwater; EM Fields; H₂O/CO₂ Condensation at Poles; Subsurface Redox Profiles; Exogenic Influx; etc.

Targeted Science

One instrument drives all.

High Resolution Imaging (Visual, IR, Spectroscopic) for landing site selection and reconnaissance; Exogenic Influx & Chemistry; Trace Gas Sinks, Sources, and Transport; Groundwater, etc.

Special Landing Zones are Enabled

Special Locations, such as Poles, Valles Marineris, Southern Highlands, Lowest Altitude, Caves, etc.

3D/4D is the Science

- Global Coverage
- Networks
- Causality
- Processes
- Scouts

Atmospheric Erosion Drivers; Trace Gas Sinks, Sources, and Transport; Weather Dynamics; Wind Dynamics; Dust & Aeolian Dynamics; Surface-Subsurface Exchange of Vapor Dynamics/Transport.

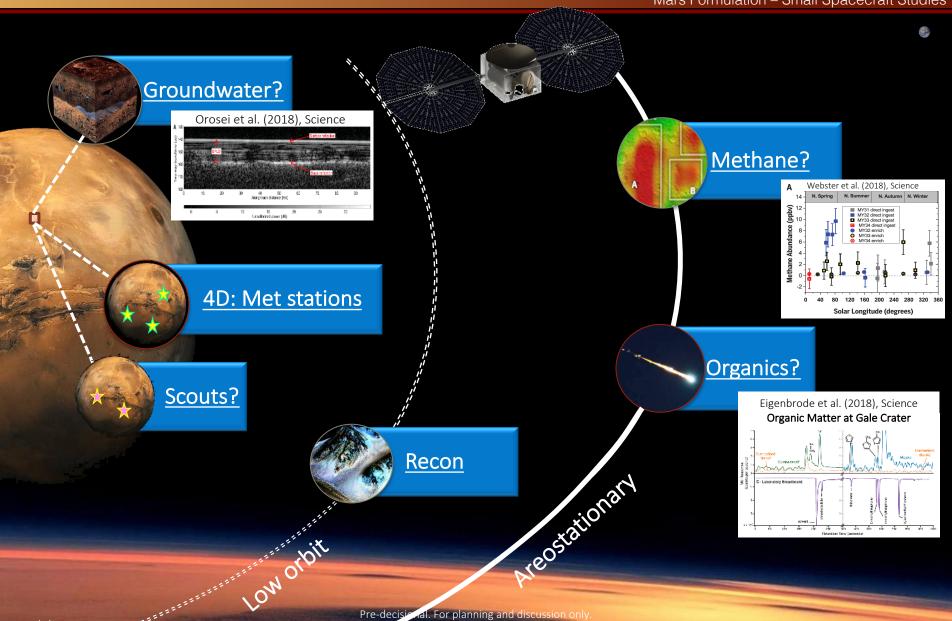
3D Seismology; 3D Radar; EM Propagation, etc.

High value science at low cost, complementary to MSR.

Compelling Smallsat Science: From Orbit and On the Surface



Mars Formulation - Small Spacecraft Studies



Timely & recent decadal class science questions well suited for

Mars small spacecraft in Mars orbit.

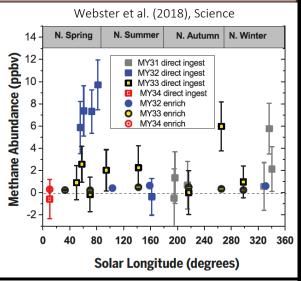
Trace Gas Localization

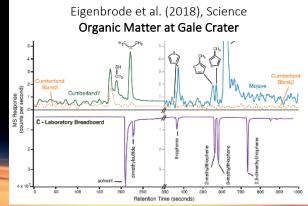
- <u>Questions</u>: where is methane coming from, where is it destroyed? Is the source abiotic or biotic (extinct vs extant).
- Areostationary configuration can answer this question by monitoring one constant field of view.

Delivery of Organics by Meteoroids

- Questions: How much material, especially organics, is delivered to the surface (Exogenic Influx)
- CCD whole-disk monitoring device with selected filters staring from areostationary orbit can address this question.

Origins & sinks of variable CH₄ and origins of organics





 Timely & recent decadal class science questions well suited for Mars small spacecraft for Mars surface/subsurface.



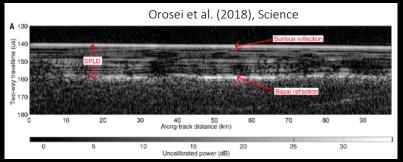
Groundwater

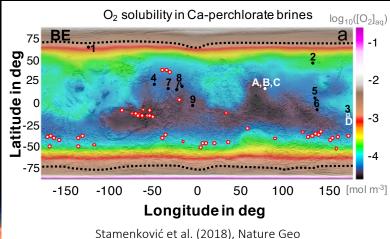
- <u>Questions</u>: Is there liquid water in the subsurface, what is its chemistry?
- Small TEM (transient electromagnetic) sounders can answer this question.



- Questions: What is the spatial and temporal variability in key properties across the surface and subsurface (with surface assets or penetrators)?
- Weather, sniffers, EM field, subsurfaceatmosphere exchange (global coverage of fundamental fast-changing processes)

Explore subsurface habitability by seeking evidence of groundwater & trace gases.





Three Key Methods to Get Small Spacecraft to Mars



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Piggyback to Mars

Pro: Cheap, direct delivery
Con: Few reliable options

Mass: varies

Frequency: > 2 years



2. Earth Rideshare + Propulsion

Pro: Cheap, lots of options

Con: Secondary, need propulsion

Mass: 100-400 kg

Frequency: > 6 per yr

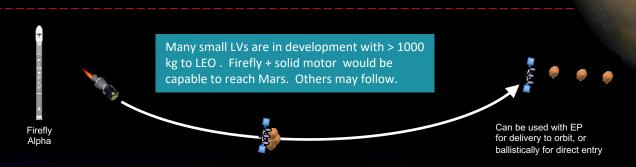


3. Dedicated Launch

Pro: Custom, full control

Con: Kick stage, low TRL

Mass: 100-300 kg Frequency: 2021+

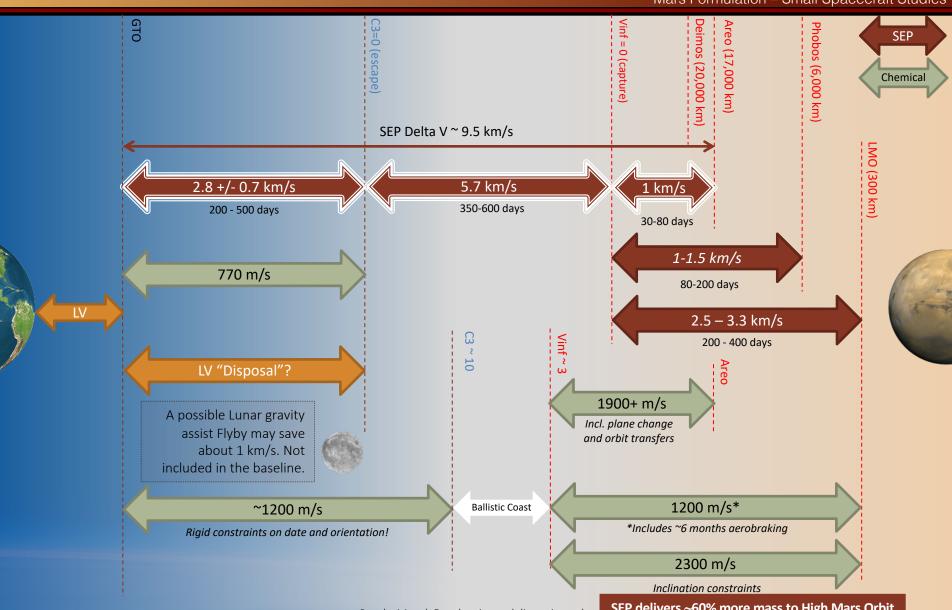


Primary

Path to Mars Orbit Via Rideshare







Promising Small Launch Vehicles for Mars



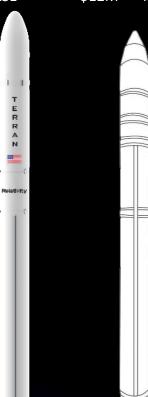
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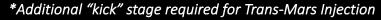
Company	Rocket	Cost	1st Launch	Fairing	LEO	Mars Entry*	LMO* (w/ AB)
FireFly	Alpha	\$15M	late 2019	2.0	1000 kg	200kg	130 kg
Relativity Space	Terran 1	\$10M	late 2020	1.9	1250 kg	250 kg	160 kg
ABL Space	RS1	\$12M	late 2020	1.8	1200 kg	240 kg	150 kg





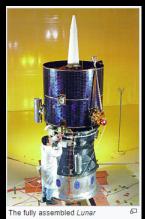


Relativity



Assumptions

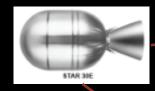
- Use STAR 30E kick stage
- May need to be stretched
- 20 kg for adapter
- 300 km LMO uses biprop to 24hr orbit
- 6 mos. for aerobraking

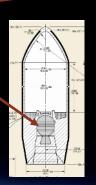


The fully assembled Lunar Frospector spacecraft is shown mated atop the Star 37 Trans Lunar Injection module



Lunette Concept (2009) Star 27, 2 km/s LOI







The cost information contained in this document is of a budgetary and planning nature and is intended for information purposes only. It does not constitute a commitment on the part of JPL and/or Caltech.

MaSMi (AXE) Interplanetary EP Thruster

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- MaSMi thruster ideally suited for small EP missions to Mars
 - Magnetically Shielded Miniature Hall Thruster
 - Developed and tested at JPL
 - Recently licensed to Apollo Fusion for production (labeled Apollo Xenon Engine or AXE)
- Shielding

 10x lifetime vs. conventional Hall

Lifetime: 10,000+ hrs

Production: 2020

Mass: < 5 kg

Xenon: 200+ kg



Max Power	1075 W		
Min Power	160 W		
lsp	1935 s		
Thrust	69 mN		
Efficiency	51%		



SN



Apollo Fusion is licensing technology from JPL to create a new high-power Hall thruster called AXE that offers a longer lifetime than existing systems. Credit: R. Conversano, Jet Propulsion Laboratory, California Institute of Technology

WASHINGTON — Satellite electric propulsion startup Apollo Fusion is expanding its product line through an agreement with NASA's Jet Propulsion Laboratory, giving it access to advanced Hall thruster technology.

The Silicon Valley-based company said May 7 that it signed a deal that gives it an exclusive worldwide commercial license for JPL's Magnetically Shielded Miniature, or MaSMi, Hall thruster technology, as well as a contract to provide JPL with three thrusters that use that technology.

AREO TGL: High Orbit Concept Case Study

Areostationary Trace Gas Localizer



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Features

Mass: ~190 kg dry mass

Target: Mars – Areostationary Orbit

Configuration: Single s/c, constellation

Launch: Secondary P/L on ESPA Grande

Cruise: Solar electric propulsion

Risk Class: D

Lifetime: ~3 years in orbit then

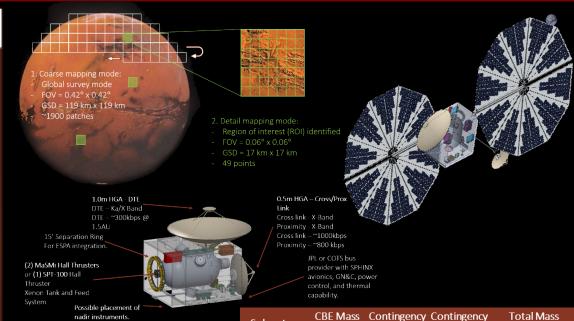
replenished

Telecom: Ka-Band, Direct to Earth,

MAVEN-class data rates.

Science & Instruments

- Localization and diurnal concentrations of methane and water and its isotopologues.
- Spatial Heterodyne Spectrometer (JPL)
- Camera





Subsystem	[kg]	[%]	[kg]	(CBE+Cont)[kg]
ACS	8.1	10%	0.8	8.9
C&DH	1.7	13%	0.2	1.9
Mechanical	29.8	15%	4.5	34.3
Payload	11.0	15%	1.6	12.6
Power	35.9	8%	2.7	38.6
Propulsion	27.7	10%	2.8	30.5
RCS	10.5	15%	1.6	12.1
Telecom	16.5	8%	1.3	17.8
Thermal	7.3	15%	1.1	8.5
S/C Dry Mass	148.5			
Contingency* o	n CBE [kg]	11%	16.6	
CBE + Continge	ncy [kg]			165.1
System Margin	* [%]	15%		24.8
Dry Mass + Syst	tem Margin [kg]		189.8
Propellant Mas	s [kg]			153.2
S/C Wet Mass [kg]			343.0
System Target I	Mass [kg]			450.0

Surface/Subsurface Concept Case Study

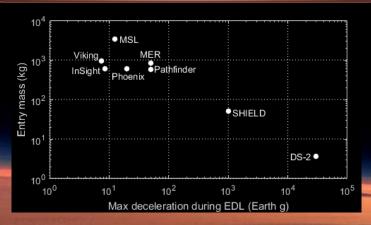
SHIELD Impact Lander Concept

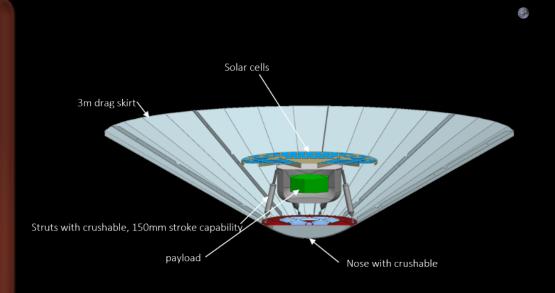


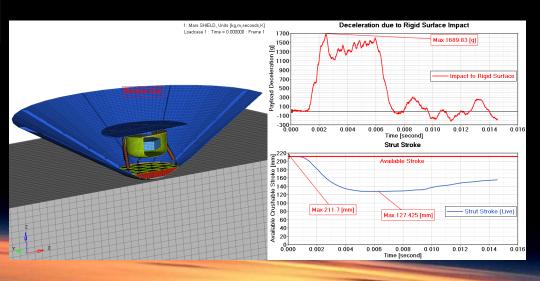
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SHIELD – Small High Impact Energy Landing Device

- SHIELD enables the transportation of small scientific payload affordably to the surface;
- Mass ~50kg, 60 m/s, impact load range
 1000 g 2000 g.
- Total science payload up to 6 kg.
- Science payload can vary, investigating options for mobility.
- Science goals of high priority for Decadal science, MEPAG, and HEO SKG's.







Summary Thoughts and Discussion



Mars Formulation - Small Spacecraft Studies

Several emerging trends are creating a unique new opportunity for *compelling Mars science* missions at *radically reduced cost* relative to Discovery

- Low-cost rideshare and new commercial launch vehicle providers
- Efficient smallsat-scale EP solutions for Mars transfer from GTO
- Low-complexity hard-lander concepts for Mars surface access
- Low-SWaP avionics and instrument capabilities
- \$100M \$300M represents a technological "sweet spot" with high science return above current SIMPLEx \$55M cap (insufficient for high-value planetary science missions) but *far below* Discovery total mission cost

How can/should the international Mars community leverage this opportunity?

- Refine focused Mars science mission concepts suited to smallsat implementation
- Advocate for a new class of Mars smallsat missions in upcoming NASA Decadal Survey
- Consider smallsat missions for critical Mars infrastructure (e.g., telecom relay, hi-res recon...)
- Seek international partnerships leveraging complementary capabilities to further affordability



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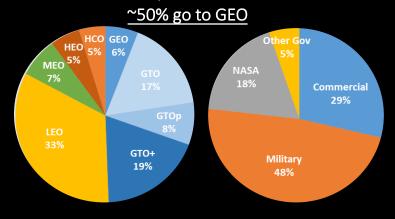


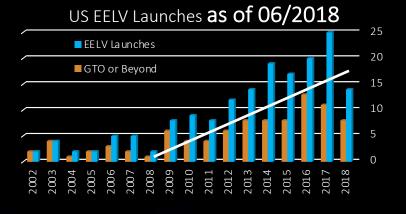


Compiled internal database of US EELV launches: Atlas V, Delta 4, Falcon 9



Statistics since 2002: <u>168 total launches</u> of Atlas V, Delta 4, and Falcon 9.





We can reliably count on an affordable GTO launch opportunity as a secondary payload brokered by one of the brokers and/or integrators.